### TABLE OF CONTENTS

	rage
Chapter 1. Introduction	1
Stochastic population models in ecology and conservation biology	1
A note on transition matrix methods	3
Dissertation scope	4
Chapter 2. The Effect of Fire on the Population Viability of an Endangered Prairie Plant	
Introduction	8
Methods	11
Results	23
Discussion	32
Literature cited	43
Chapter 3. The Effect of Stochastic Technique on Estimates of Population Viability from Transition Matrix Models	
Introduction	55
Methods	58
Results	69
Discussion	75
Literature cited	86

# TABLE OF CONTENTS, CONTINUED.

		<u>Page</u>
Corre	Ooes Correlation among Vital Rates Matter? The Effect of Elation Structure, Vital Rate Distribution, and Species	02
on Estimates of Population Viability		93
	Introduction	94
	Methods	97
	Results	109
	Discussion	116
	Literature cited	123
Chapter 5. Conclusion		129
	A brief review of matrix model applications	129
	Goals and conclusions of this dissertation	130
	Considerations for stochastic matrix modelers	134
Bibliography		137
Appendix		155

### LIST OF FIGURES

<u>Figure</u>		Page
1.1.	A transition matrix model. Matrix selection involves randomly selecting whole matrices (e.g., year 1, 2, or 3) at each time step of the simulation, while element selection involves building a new matrix from the mean and variance of each element.	4
2.1.	Conceptual model of the life cycle pathways of <i>Lomatium bradshawii</i> . Each arrow represents possible transitions plants can make from one year to the next. Dashed lines pointing to the seedling stage indicate reproduction. Double-headed arrows indicate regression to a smaller stage or growth to a larger stage. Stages identified in this model are first year seedling (S), one to two-leaved vegetative plants (V2), vegetative plants with three or more leaves (V3), and reproductive plants with one (R1), two (R2), or three or more (R3) umbels.	e 15
2.2.	Stochastic population growth rate ( $\lambda_s$ ) within each site and burning treatment for a) element selection (calculated with RAMAS/stage) and b) matrix selection (POPPROJ2). Each value is a median of 2,000 iterations with 95% confidence intervals.	27
2.3.	Extinction probability in burned and unburned stochastic environments calculated through a) element selection (calculated with RAMAS/stage) and b) matrix selection (POPPROJ2). All runs were 100-yr simulations iterated 1,000 times. Initial population sizes were 800 plants, and extinction was defined as falling below 10 individuals. Vertical lines are 95% confidence intervals.	28
2.4.	Stage-summed elasticities for populations in burned and unburned environments at a) Rose Prairie and b) Fisher Butte based on weighted mean matrices from six years of observations. Error bars represent bootstrapped 95% confidence intervals.	31

# LIST OF FIGURES, CONTINUED.

<u>Figure</u>		<u>Page</u>
3.1.	Probability densities of some statistical distributions fit to examples of observed values of transition rates recorded over several years of observation. Each column illustrates a different distribution (beta, truncated gamma, truncated normal, triangular, and uniform) and each row represents the fit of these distributions to the data listed at the right, which are selections from among the data sets used in this paper. These data represent the observed values for a particular transition, as indicated in the notes at the far right. Note that the truncated normal distribution is truncated at both tails and the truncated gamma is truncated only on the right, and the degree of truncation differs substantially among observed data sets.	64
3.2.	Mean proportional difference ( $\pm 1$ SE) in stochastic population growth rate ( $\lambda_s$ ) between matrix selection and the element selection procedures. Six statistical distributions were used for the element selection method: beta, observed/discontinuous (disc), truncated gamma (gam), truncated normal (norm), triangular (tri), and uniform (unif). Two survival constraint methods, resample and rescale, were also compared. Bars with the same letter did not differ at the 0.05% level (Fisher's protected LSD). Asterisks (*) indicate a significant difference between the stochastic growth rate calculated via matrix selection and each element selection method.	
3.3.	Evaluation of bias in transition means (top panels) and standard deviations (middle panels). The correlation between change in $\lambda_s$ and bias in mean is shown (bottom panels) along with the linear models. Mean bias in standard deviation was omitted from the models because it was not significant in the multiple regressions ( $P$ =0.10-0.66). Left panels use unweighted averages and right panels use averages weighted by elasticities.	
4.1.	Mean ( $\pm 1$ SE) proportional effect of correlation on stochastic growth rate ( $\lambda_s$ ) for five plant species. Bars with the same letter do not differ at the 0.05 level of probability (Fisher's protected LSD) and asterisks indicate significant difference from zero ( $*0.05>P$0.01$ , $**P#0.0001$ ).	111
4.2.	Mean ( $\pm 1$ SE) bias in Spearman rank correlation coefficients ( $R_{\rm s}$ ) for each of five plant species examined. Bias was defined here as the average difference between mean observed and simulated $R_{\rm s}$ .	112

# LIST OF FIGURES, CONTINUED.

Figure	Page
4.3. Mean ( $\pm 1$ SE) absolute value of observed of ( $ R_s $ , top), difference between average position (middle) and ratio of number of positive to each of five species included in this study.	tive and negative $R_{\rm s}$ values
4.4. Mean ratio of positive to negative $R_s$ values including correlation structure on estimates Ratios less than 1.0 indicate negative corre values. The fitted linear regression line (daparameters are also shown.	s of stochastic growth rate $(\lambda_s)$ . lations outnumber positive
parameters are also shown.	113

### LIST OF TABLES

<u>Table</u>		Page
2.1.	Four-way transition frequency table used in the loglinear analysis (Table 2). Counts of individuals summed across the five years of the study are shown for each combination of six initial classes, six fates, two locations, and three burning treatments.	17
2.2.	Loglinear analysis of the effects of burning treatment and location on stage-specific plant fates. The explanatory variables are initial class (C), treatment (T) and location (L), and the response variable is fate (F). Relevant comparisons for each test are shown as differences between two models, and their corresponding <i>P</i> -values are shown in bold type.	18
2.3.	Mean transition matrices and variances for each site, treatment, and year (1988-93, n=5). Fertilities are found on the top row of each matrix. Probabilities for stasis are along the main diagonals, regression to smaller stages are above the diagonals (excluding the top row), and growth probabilities are below the diagonals in each column. Stages are defined in Methods.	24
2.4.	Elasticities for weighted mean matrices (1988-93) for each site and burning treatment. Values for fertility are displayed on top rows. Stasis values are found on the diagonals, growth below the diagonals, and regression above (excluding fertilities). The transition with the highest elasticity is shown in bold for each matrix, and the bottom row is the sum ( $\Sigma$ ) of the upper rows for each column.	30
2.5.	Fruits encountered in soil samples from four <i>Lomatium bradshawii</i> populations. Samples (N) were taken after seedling emergence and before fruit dispersal to detect a persistent soil seed bank.	33
3.1.	Study species included in this analysis, number of populations and years observed, number of observed matrices and stage categories, habitat, and ecoregion. All species are herbaceous perennial plants.	59
3.2.	Examples of stochastic models, their use of statistical distributions for varying transition elements, and methods of constraining survivals to 100%.	63
3.3.	Split-plot ANOVA for the effects of species, statistical distribution of input variables, and survival constraint method on the proportional change in $\lambda_s$ relative to the matrix selection procedure (NDF and DDF are numerator and denominator degrees of freedom).	70

<u>Table</u>		<u>Page</u>
3.4	Pearson correlation coefficients ( $R$ ) for each of seven methods of incorporating environmental variability to calculate stochastic population growth rate ( $\lambda_s$ ). Correlations with $\lambda_s$ calculated using the resample survival constraint method are above the diagonal, while those derived via the rescale method are below ( $P\#0.0001$ in each case).	76
4.1.	Study species included in this analysis, number of populations and years observed, number of observed matrices and stage categories, habitat, and ecoregion. All species are herbaceous perennial plants.	98
4.2.	Examples of stochastic models, their inclusion of correlation structure, and use of statistical distributions for varying transition elements.	103
4.3.	Split-plot ANOVA for the effects of statistical distribution of input variables and species on the proportional change in $\lambda_s$ when correlations among vital rates are included (NDF and DDF are numerator and denominator degrees of freedom).	110
4.4.	Pearson correlation coefficients ( $R$ ) for estimates of stochastic population growth rate ( $\lambda_s$ ) derived from five methods of incorporating environmenta stochasticity. Correlations with $\lambda_s$ calculated by including correlation structure are above the diagonal ( $P\#0.0001$ ), while those estimated with correlation structure are below ( $P\#0.0016$ ). Values on the diagonal (in bold) are correlations between $\lambda_s$ estimates with and without correlation structure ( $P\#0.0001$ in all cases)	
	without correlation structure ( $P#0.0001$ in all cases).	11/